

I know it when I quantify it: ecological momentary assessment and recurrence quantification analysis of emotion dysregulation in children with ADHD

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Abstract Two studies examined the feasibility, utility, and validity of Ecological Momentary Assessment (EMA) and Recurrence Quantification Analysis (RQA) in assessing emotion dysregulation in children with Attention-Deficit/Hyperactivity Disorder (ADHD). In Study 1, 11 parents of children with ADHD ages 8–11 completed EMA-based ratings of their children's mood three times daily for 28 days (84 ratings total) and questionnaires regarding their children's emotion dysregulation. RQA was used to quantify the temporal patterning of dysregulation of the children's mood. In Study 2, five children ages 8–11 completed EMA-based ratings of their mood three times daily for 28 days. Results supported the feasibility and validity of the parent report EMA protocol, with greater intensity, variability, and persistent patterning of variability associated with greater emotion dysregulation. Results did not support the validity of the child report protocol, as children were less likely to complete ratings when emotionally distressed and demonstrated substantial response bias.

Keywords ADHD · Emotion dysregulation · Ecological momentary assessment · Recurrence quantification analysis

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Introduction

Emotion dysregulation occurs when individuals are unable to successfully modulate their emotional states to fit their internal or environmental needs (Cole et al. 2004). Emotion dysregulation is a multidimensional construct, incorporating emotional reactivity, intensity, variability, and predictability (Rosen and Epstein 2010; Rosen and Factor 2012). Zeman et al. (2006) describe emotion dysregulation as “one of the most robust and critical constructs in child development” (p. 156). Emotion dysregulation in children is linked to a wide variety of maladaptive outcomes, including externalizing and internalizing behavior (Eisenberg et al. 2001), irritability and aggression (Galanter and Leibenluft 2008), emotional outbursts (Melnick and Hinshaw 2000), and social dysfunction (Rosen et al. 2007).

Emotion dysregulation has increasingly been identified as a construct of importance among children with Attention-Deficit/Hyperactivity Disorder (ADHD; Barkley 2010; Skirrow et al. 2009). Children with ADHD experience more emotional instability, are less able to regulate emotions, and demonstrate greater irritability and emotional explosiveness than typically functioning children (Skirrow et al. 2009; Sobanski et al. 2010). Barkley (2010) has posited that emotion dysregulation is a core component of ADHD and has termed the pattern of emotional reactivity, intensity, and variability commonly experienced by children with ADHD as “emotional impulsivity.” There is considerable variability in emotion dysregulation among children with ADHD, and studies have identified a subset of children with ADHD who demonstrate a pattern of particularly severe emotion dysregulation (Melnick and Hinshaw 2000; Sobanski et al. 2010). Indeed, children with ADHD who demonstrate more emotional impulsivity (i.e., variability characterized by intense shifts in emotion)

experience greater emotional and behavioral impairment (Rosen and Factor 2012). Interestingly, previous research has indicated that it is shifts in overall emotion, rather than positive or negative emotion alone that is most related to emotional and behavioral impairment in children with ADHD.

Emotion dysregulation is thought to be linked to a pattern of emotionally driven behavioral difficulties that results in a pattern of mixed internalizing–externalizing problems that is fundamentally unique from the “pure” form of externalizing difficulties (Keiley et al. 2003). Indeed, children with emotion dysregulation and externalizing difficulties demonstrate more emotional distress, greater problems in peer relations, and difficult and unadaptable temperamental characteristics (Eisenberg et al. 2010; Keiley et al. 2003), while the “pure” externalizing pattern is related to conduct difficulties, covert behavioral difficulties, and harsh parenting practices (Eisenberg et al. 2010; Keiley et al. 2003). This pattern of emotion dysregulation manifesting through emotion distress and emotionally driven behavior problems has been evidenced in both typically functioning children (Zeman et al. 2002) and children with ADHD (Rosen and Factor 2012).

Emotion dysregulation is a complex, continuous, multidimensional, and transdiagnostic process that has proved hard to define and even harder to quantify (Cole et al. 2004; Zeman et al. 2006). Indeed, the term “emotion dysregulation” actually encompasses a broad range of processes occurring both discretely (i.e., excessive immediate emotional arousal) and longitudinally (i.e., instability of emotional state over time). Emotion regulation is a homeostatic process, whereby discrete emotional arousals are regulated around a temporally determined “set point” (Larsen 2000; Chow et al. 2005). According to the homeostatic model, dysregulation may reflect a pattern of extreme departure from the adaptive set point, repeated variability around the set point, unpredictable variation around the set point, or even variation in the set point itself (Larsen 2000). Different facets of emotion dysregulation have been associated with distinct forms of psychological dysfunction across patient populations (Eaton and Funder 2001; Rosen and Epstein 2010). Emotion dysregulation in children has most commonly been measured through use of retrospective report instruments or laboratory-based assessment (Porges et al. 1994; Shields and Cicchetti 1997). Rating scales and physiological assessment both provide considerable information regarding emotion dysregulation, but neither method is able to fully capture the dynamic temporal structure of both discrete and longitudinal emotion dysregulation that unfolds over time as the child attempts to control reactivity and maintain emotional homeostasis while dealing with the challenges of their day-to-day life.

It is clear that unconventional methods and statistical approaches are necessary for assessing emotion dysregulation. Ecological Momentary Assessment (EMA) holds tremendous promise as an alternative method of assessing both discrete and temporal facets of emotion dysregulation in children. EMA (also known as Experience Sampling) collects real-time information about mood states from participants directly on personal data assistants (PDA) within the context of their typical daily lives. EMA provides more accurate response data and is substantially less susceptible to cognitive biases than retrospective or summary report (Shiffman et al. 2008). Data provided by ecological momentary assessment allow for an ecologically valid aggregating of both intensity and variability of emotions over time.

The temporal structure of emotion dysregulation requires not just temporally sensitive assessment methodologies but temporally sensitive statistical approaches as well. Conventional aggregate statistics (i.e., mean, standard deviation) provide useful information regarding intensity and degree of variation, but also collapse data across time and thereby eliminate the information about temporal *patterns* of variability in a data series (Carello and Moreno 2005). By contrast, nonlinear methodologies such as Recurrence Quantification Analysis (RQA) have been developed to capture the dynamic structure of an individual participant's temporally dependent data series (Pellecchia and Shockley 2005). RQA uses recurrence plots to assess and quantify temporally derived patterns of stability and variability within time-series data (Pellecchia and Shockley 2005). RQA is highly robust as it assumes neither stationarity nor linear continuity of data over time (as is assumed by conventional linear methods of time series analyses such as ARMA models or autocorrelation) and thus allows for the quantification of continuous or discrete *patterns* of variability and stationarity/nonstationarity. RQA has shown applicability in detecting nonlinearities in the temporal structure of EMA-based self-reports of mood and emotional well-being (Riley and Van Orden 2005). RQA thus represents a powerful new tool for assessing differences among individuals in temporal patterns of emotion dysregulation.

We present two studies examining the feasibility and utility of collecting longitudinal information about emotional states in a sample of children with ADHD. In the first study, we examine parent-reported data collected via EMA over a 4-week period. Using both aggregate and RQA indicators to describe the EMA data, parental EMA ratings of their children's mood are compared to parent-reported ratings of emotion dysregulation and internalizing and externalizing behavior to examine the concurrent and discriminate validity of the EMA methods and RQA statistical indicators. We predicted that parents would be able to

demonstrate adherence to the EMA protocol, as indicated by completion of >80 % of assessment intervals. Further, we predicted that aggregate and RQA indicators of intensity, variability, and patterning of EMA-based parent-reported ratings of children's mood would demonstrate moderate correlations with questionnaire-based ratings of emotional lability and distress. Specifically, higher questionnaire-based ratings of emotional lability and distress would be associated with greater intensity and variability of EMA-based ratings of mood. Temporal patterning of mood variability would also be associated with questionnaire-based emotional lability and distress, with greater emotional lability and distress evident among children with persistent, rather than intermittent patterns of variability. Finally, given that emotion dysregulation in children is typically manifested through a pattern of mixed internalizing–externalizing behavior (Rosen and Factor 2012), we predicted that both aggregate and temporal patterning of mood variability would be associated with both internalizing and externalizing difficulties in children with ADHD.

In the second study, we examine the feasibility and utility of collecting EMA ratings from children with ADHD. Research has yielded inconsistent results regarding children's abilities to accurately self-report their own emotional states (Zeman et al. 2007) and adhere to child-reported only EMA protocols (Suveg et al. 2010). Studies have also suggested that parent- and child reports are often highly discrepant (De Los Reyes and Kazdin 2005; Whalen et al. 2006). We hypothesized that embedding EMA data collection for child-report within a parent-reported EMA protocol would yield acceptable adherence, as indicated by completion of at least 80 % of assessment intervals. Given the emotionally labile ADHD patient sample selected for this study, we hypothesized that children's reports would demonstrate significant response bias. Specifically, we predicted that children's emotional intensity would interfere with their ability to complete EMA assessment procedures, such that parents would rate children as demonstrating poorer mood and greater anger during intervals where the child was non-adherent than during intervals where the child was adherent, and that children would demonstrate evidence of use of response biases (i.e., positive skew, dichotomous responding).

Study 1

Methods

Participants

Eleven children (9 boys, 2 girls) aged 8–11 years ($M = 9.45$, $SD = 1.04$) and their families participated in

the present study. To ensure that the sample included children with an appropriate range of clinically impairing emotion dysregulation difficulties, participants were recruited from a sample of children whom had been clinically referred for services related to emotion dysregulation and ADHD. Families were enrolled in the study prior to initiation of clinical services. To ensure consistency across the EMA protocol, children were only eligible for participation if they were resident in a single home (i.e., two-parent or single-parent family) full-time over the course of the study. Seventeen of the 23 children referred to the clinical service were eligible for participation. The six children who were excluded were resident in more than one home (i.e., parental joint-custody). Fifteen of the 17 families initially agreed to participate; however, 2 families failed to complete the full EMA assessment protocol, and 2 additional families experienced technical difficulties (i.e., equipment failure) that prevented them from completing the EMA protocol. Thus, final analyses reflect the 11 families that fully completed the EMA assessment protocol.

All 11 children in the current study had been previously diagnosed with ADHD (9 Combined Type, 2 Inattentive Type), while 9 had also received at least one comorbid mood, anxiety, or behavioral diagnosis ($M = 2.27$, $Mode = 2$). Ten of the 11 children were receiving medication treatment for ADHD concurrent to participation, with medication status and dose remaining consistent throughout the study for all participants. Ten of the 11 children were identified as Caucasian (1 of 11 identified as African-American). Three of the 11 families indicated Medicaid as their child's primary form of health insurance, while the other 8 reported private or employer-sponsored health insurance.

Measures

Ecological Momentary Assessment. Parents provided ratings using a Palm[®] Z22 Personalized Data Assistant (PDA), which had been programmed using Purdue Momentary Assessment Tool software (PMAT; Weiss et al. 2004). The PDA set off alerts at three specific predetermined intervals (i.e., before school, after school, and evening) requested by parents to be compatible with the family's schedule. The PDA sounded an alarm and turned itself on at all programmed assessment intervals, and participants were not able to turn the PDA off until all assessment intervals had been completed. Participants were able to complete intervals up to 90 min following an alarm. Parents were prompted to complete ratings at each time point while directly observing their child. At each time point, parents were asked to report on their child's current mood. Parents rated their child's mood (i.e., "what is your child's mood right now?") at the time of the assessment using a visual

analog scale (VAS) at each assessment interval. Mood was rated on an 11-point scale ranging from -5 to $+5$, whereby -5 = “much worse mood than usual,” 0 = “typical mood for my child,” and $+5$ = “much better mood than usual.”

Questionnaires

The *Emotion Regulation Checklist* (ERC; Shields and Cicchetti 1997) was used to assess parent's reports of their children's global emotion dysregulation. The ERC is widely used as a broad-spectrum measure of emotionally dysregulated behavior and has demonstrated substantial reliability and validity (Shields and Cicchetti 1997). The ERC is a 24-item parent-report that yields two subscales: Emotional Lability/Negativity and Emotion Dysregulation (Shields and Cicchetti 1997). The Lability/Negativity scale measures dysregulated negative affect, emotional lability, and lack of emotional flexibility through items such as “exhibits wide mood swings,” “is easily frustrated,” “is prone to angry outbursts,” and other items. The Emotion Dysregulation scale is actually comprised of items more relevant to appropriate socioemotional expression and emotional awareness than emotional variability, as it is comprised of items such as “is whiny/clingy with adults,” “takes pleasure in the distress of others,” “can say when he/she is experiencing negative emotions (*reverse scored*)”, and other such items (Shields and Cicchetti 1997). Within the present study, the Emotional Lability/Negativity scale was used as an indicator of emotional intensity and variability, and the Emotion Dysregulation scale was used as an indicator of socioemotional expression. Accordingly, it was hypothesized that the Emotional Lability/Negativity scale would be more closely associated with the aggregate and temporally patterned measures of mood variability than would the Emotion Dysregulation scale.

The *Child Behavior Checklist* (CBCL; Achenbach 2001) was used to assess the extent to which emotion dysregulation manifested itself through internalizing/externalizing behaviors in children. The CBCL is a 113 item clinically normed measure of parents' perceptions of their children's emotional and behavioral problems, yielding two composites (Internalizing Problems and Externalizing Problems). Numerous studies have indicated that emotion dysregulation is often manifested through both internalizing (i.e., emotion distress, emotional ‘meltdowns’) and externalizing (i.e., reactive aggression, ‘tantrums’) behavior in typically functioning children (Zeman et al. 2002), while a recent study by the lead author of this article found strong associations of emotional impulsivity with internalizing and externalizing behavior among children with ADHD (Rosen and Factor 2012). The Internalizing Problems scale was used within the present study as an indicator of emotional negativity and distress, and the Externalizing

Problems scale was used as an indicator of behavioral difficulties.

The *Children's Depression Inventory-2nd Edition* (CDI-2; Kovacs 1992) was used to assess children's perceptions of their affective functioning. The CDI-2 is a 27-item child-report measure that assesses the presence of depressive symptoms in children. The CDI-2 has been clinically normed and provides *T*-scores that are normed by age and gender (Kovacs 1992). The CDI-S was used in the current study as an index of children's perceptions of their own affective difficulties.

Procedures

Parents of participants provided consent and completed questionnaires regarding their child's internalizing behavior, externalizing behavior, and emotion regulation at the baseline assessment. Parents also received training in completion of the EMA protocol. Parents then completed ratings with the PDA three times daily for a period of 28 days. The 28-day assessment period was selected over the shorter (i.e., 1 week) periods utilized in previous studies (i.e., Whalen et al. 2006, 2009; Suveg et al. 2010) to ensure that assessments captured a full temporal range of emotional variation and provided an adequate number of rating points to complete nonlinear analyses. Indeed, preliminary data from the present study indicated only moderate correlations ($r_s(11) = 0.33\text{--}0.38$) between the mean and standard deviation of the parent's first week of EMA ratings and the parent's second week of EMA ratings. Although all participants were initially scheduled to complete 84 intervals ($3 \times$ daily for 28 days), variation in participant's schedules and intermittent technical difficulties resulted in the number of scheduled assessment intervals ranging from 69 to 84. Parents were instructed to return to the laboratory once per week to have data uploaded and were provided with an opportunity to adjust the schedule of PDA alerts for that week. The data in the current study were collected as a part of the initial assessment phase of an open trial of a clinical psychosocial intervention, and thus monetary compensation was not provided. However, participation was voluntary and not required for the child to be eligible to receive the intervention. Only 2 of the 17 families that were eligible to participate in the study refused to participate, with the time-intensive nature of the assessment protocol cited as the primary reason for refusal. All procedures within the present studies were approved by the local Institutional Review Board.

Statistical analytic plan

Conventional EMA indicators. Intensity of mood was indicated within the current study by the mean of the

absolute value of all completed EMA ratings of mood. Mood ratings ranged from -5 to $+5$, and thus mean of the absolute value of the mood ratings was a more appropriate indicator of intensity than mean of the true ratings as it reflected the average amplitude of *all* emotional arousals regardless of valence. Absolute value of the mood ratings was used only to calculate mean, while true values of the ratings were used to calculate all other statistics. Greater mean absolute value indicated greater aggregate mood intensity. Variability of mood was indicated by the standard deviation of the true mood ratings, with greater standard deviation indicating more variable mood.

RQA indicators. Recurrence Quantification Analysis (RQA) was used to quantify the dynamic temporal structure of the EMA-based ratings of mood to assess patterns of emotion dysregulation. RQA is conducted on an individual temporal data series and yields statistics that quantify specific facets of the fluctuation patterns of a temporal data series that may then be used in conventional inferential analyses. All RQA analyses were conducted using a *delay* = 1, *line length* = 2, and an *embedding dimension* = 1 in accordance with Iwanski and Bradley's (1998) recommendation for short data sets. Radii were set to 0 in all RQA analyses so that only equivalent mood values were counted as recurrent data points.

RQA provides an array of statistics that capture specific independent qualities about the temporal relations among the data points of a data series. Within the present study, the RQA variables %Recurrence (%REC), MeanLine (MnL), Entropy (ENT), and Trend (TND) statistics were examined to assess the patterns of emotion regulation (see Webber and Zbilut 2005; Pellecchia and Shockley 2005 for statistical formulas and interpretation). %REC refers to the percentage of values that are recurrent in the data series, with higher %REC suggesting less frequent mood variability across the course of the time series. MnL refers to the average length of strings of identical data values that co-occur on adjacent measurement trials, with greater MnL indicating more mood stability over the course of the time series. High correlations between MnL, %REC, and SD in single dimension data series are expected when data series are anchored around a central rating point and indicate that variability across the data series is a function of both recurrence and stability of arousals.

ENT refers to Shannon Information Entropy (Shannon 1948) and reflects the uniformity of the frequency distribution of line lengths (series of recurrent values) within the data series. Within the present study, ENT was used as an indicator of the *patterning of variability* across the time series. As illustrated by Fig. 1, Lower ENT (more uniformly distributed line lengths) indicates that the *variability* of the mood ratings is *persistent* across the time series, while higher ENT (more unevenly distributed line

lengths) indicates that the *variability* of the mood ratings is more *intermittently* distributed at different points along the time series. TND quantifies the stationarity of data series. Homogeneously distributed ratings will produce TND values near zero, while positive or negative TND indicates nonstationarity within the ratings. Absolute TND was thus used in the present study as an indicator of episodicity within the present study. In contrast to ENT, TND measures the stationarity (i.e., episodicity) of the *data series*, rather than the patterning of the variability (see Fig. 1).

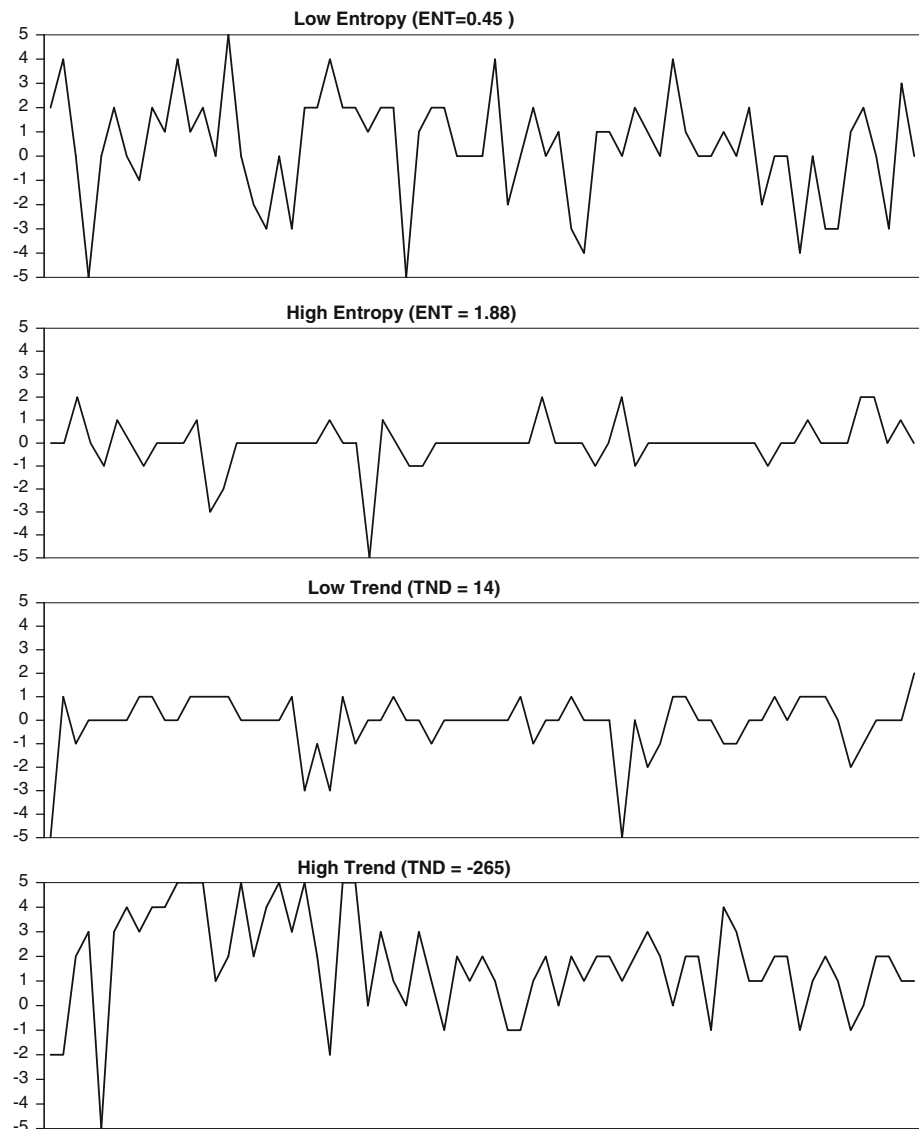
Hypothesis Testing. Concurrent validity was assessed through computation of the bivariate correlations of the EMA-based and questionnaire-based ratings. Given the small sample size and preliminary nature of the present study, all hypotheses were exploratory. It was specifically hypothesized that the EMA-based ratings of mood intensity, variability, and patterning would demonstrate moderate correlation with the conventional indicators of negativity and distress (CBCL Internalizing, ERC-Negativity, CDI) and behavioral difficulties (CBCL-Externalizing) through the previously discussed link between emotional impulsivity and mixed internalizing/externalizing difficulties (Barkley 2010; Rosen and Factor 2012). It was specifically expected that correlations would be moderate rather than large as EMA-based indicators capture substantially more complex patterns of mood variation than conventional indicators by virtue of the temporally based and repeated assessment of mood. It was expected that the EMA-based ratings of mood intensity, variability, and patterning would demonstrate discriminant validity with the conventional indicator of inappropriate socioemotional expression (ERC-Emotion Dysregulation), as the EMA ratings assessed patterning of mood variability and intensity over time rather than ability to modulate mood in social context. As ADHD is largely considered to have a chronic (i.e., non-episodic) course (Galanter and Leibenluft 2008), it was not expected that episodicity of mood would be related to any of the conventional measures of emotional negativity and distress. Given the small sample size ($N = 11$) results were interpreted primarily by the size of the correlation coefficient using Cohen's (1988) recommended heuristics of moderate ($r = 0.24-0.36$) and large ($r > 0.36$) correlations, rather than by significance testing, although significance testing was conducted and is reported.

Results

Adherence to EMA protocol

Participants' adherence to the EMA protocol was assessed by calculating the percentage of scheduled EMA assessment intervals to the number of completed EMA assessment intervals. Parents completed an average of 86.53 %

Fig. 1 Parent-reported EMA ratings of mood selected to illustrate low versus high entropy (recurrent vs. intermittent variability) and low versus high trend (chronic vs. episodic variability)



of scheduled intervals (completed $M = 66.00$, $SD = 10.43$; scheduled $M = 76.27$, $SD = 5.66$). Furthermore, 8 of the 11 participants completed greater than 80 % of scheduled intervals (with 6 of the 8 exceeding 90 %) with completion percentages ranging from 64.20 to 97.56 %.

Recurrence quantification analysis

As indicated by Table 1, RQA indicated substantial correlations among the %REC, MnL, and the linearly derived standard deviation (SD) of the dataserie, suggesting that variability, recurrence, and stability of mood were strongly interrelated. Within the present study, the large correlations [$r_s(11) = -0.84$ to -0.95] of MnL, %REC, and SD indicate that the children's patterns of emotion regulation range from a fairly stable, centralized, and intermittently variable pattern of mood regulation over time

(characterized by higher %REC and MnL and lower SD) to a relatively more unstable and persistently variable pattern of mood regulation over time (characterized by lower %REC and MnL and higher SD). ENT was correlated with SD at $r(11) = -0.52$, suggesting that ENT was substantially related to but distinct from linear SD. Children with more variable (i.e., higher SD, lower %REC, and MNL) moods also demonstrated more chronically (rather than transiently) variable mood, as reflected in a lower ENT. TND was not highly correlated with any other indicators, suggesting that there was little systematic covariation of episodicity with any of the other facets.

MnL and %REC are not bounded by the mean (as is SD) and can reflect recurrent or stable patterns of ratings at any value, and thus, it is not the case that they would be correlated with standard deviation in all cases. However, the substantial multicollinearity of these three indicators within

Table 1 Correlations of linear and RQA-derived indicators of EMA mood ratings

Measure	1	2	3	4	5
1. Absolute mean	–				
2. SD	0.89***	–			
3. %Recurrence (%REC)	–0.91***	–0.93**	–		
4. Mean Line (MnL)	–0.84***	–0.95***	0.97***	–	
5. Entropy (ENT)	–0.57 [†]	–0.52	0.53 [†]	0.46	–
6. Trend (TND)	–0.21	0.01	0.22	0.12	0.43

[†] $p < 0.10$; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; $N = 11$

the current study proscribes using all three in the correlation-based analyses with the conventional indicators of emotional and behavioral distress. Accordingly, SD was selected for use within the validity analyses as it is the most basic and easily interpretable. However, it should be kept in mind that within the present study, variability (i.e., standard deviation) is also inversely indicative of the temporal recurrence and stability of the data series. A similar pattern of validity would thus be evident in the present study if MnL or %REC was used given the structure of the data; however, this cannot be generalized to data series with a different temporal structure (i.e., not bounded around a central attractor). As ENT and TND demonstrated substantially smaller correlation coefficients with both the linear and RQA-derived statistics, both were included in all further analyses.

Validity of EMA-based ratings of mood

Bivariate correlations were conducted between the 4 EMA-based indicators of mood regulation and the questionnaire-based measures of emotional and behavioral negativity and distress to assess the concurrent validity of the EMA-based indicators (see Table 2). Large correlation coefficients were observed between the CBCL Internalizing scale and the EMA-based indicators of mood intensity (absolute mean), $r(11) = 0.43$, $p < 0.20$, variability (standard deviation), $r(11) = 0.44$, $p < 0.20$, and patterning (ENT), $r(11) = -0.56$, $p = 0.07$, such that children who were rated as having more intense mood arousals, more variable moods, and more persistent (i.e., less intermittent) patterns of variability of mood dysregulation were also rated as demonstrating more internalizing behavior. Similarly, moderate correlation coefficients were observed between the ERC-Lability/Negativity scale and the EMA-based indicators of mood intensity (absolute mean), $r(11) = 0.36$, $p < 0.30$, variability (standard deviation), $r(11) = 0.28$, $p < 0.40$, and patterning (ENT), $r(11) = -0.28$, $p < 0.40$, such that children who were rated as having more intense mood arousals, more variable moods, and

more persistent patterns of variability of mood dysregulation were also rated as demonstrating more emotional negativity. A large correlation coefficient was observed between mood intensity and the CBCL externalizing scale, $r(11) = 0.43$, $p < 0.20$; however, no other moderate or large relations were noted between the EMA mood indicators and the behavioral rating scales. A small to moderate correlation was noted between episodicity (TND) and children's questionnaire-based report of their own emotional distress as assessed by the CDI-2, such that children who were more distressed also reported slightly more emotional episodicity, $r(11) = 0.27$, $p < 0.50$, although no other EMA-derived indicators demonstrated any notable correlation with the CDI-2. Episodicity was not related to any other measure of emotional or behavioral distress in the current study. As predicted, the EMA-derived indicators of patterning of mood variability and intensity were not related to the parents' report of the child's inappropriate socioemotional expression as indicated by the ERC-Emotion Dysregulation subscale, $r_s(11) = 0.02-23$. Overall, results provided initial support for the use of the EMA-based indicators of mood regulation, as mood intensity, variability, and patterning were related to greater emotional and behavioral negativity and distress but not to children's inappropriate socioemotional expression.

Study 2

Methods

Participants

A subset of five participants (4 boys, 1 girl) aged 8–11 years from Study 1 participated concurrently in Study 2. Participation in this study was determined by selecting five consecutive referrals to Study 1 for concurrent participation in Study 2. All five children participating in Study 2 had been previously diagnosed with ADHD (4 combined type, 1 inattentive type) and were seeking clinical services for emotion dysregulation difficulties. All 5 of the participants were identified as Caucasian. 4 of the 5 children were receiving medication for ADHD, with medication status and dose remaining consistent throughout the study. 4 of the 5 children came from intact two-parent families with the other child residing with a single parent, while 2 of the 5 families indicated Medicaid as their child's primary form of health insurance.

Measures

EMA Children were asked to rate their mood *at the time of the assessment* using a visual analog scale (VAS). The

Table 2 Correlations of parent-reported EMA mood indicators and questionnaire ratings

Measure	1	2	3	4	5	6	7	8
<i>EMA indicators</i>								
1. Mood—abs. mean	–							
2. Mood—SD	0.89***	–						
3. Mood—ENT	–0.57 [†]	–0.52	–					
4. Mood—TND	–0.30	–0.23	0.47	–				
<i>Questionnaire ratings</i>								
5. CBCL—internalizing	0.43	0.44	–0.56 [†]	–0.08	–			
6. CBCL—externalizing	0.43	0.18	–0.21	0.01	0.31	–		
7. ERC—lability/Neg.	0.36	0.28	–0.29	–0.15	0.43	0.37	–	
8. ERC—emot. dysreg.	0.23	0.03	0.12	0.17	0.42	0.79**	0.30	–
9. CDI-2	0.10	0.22	0.04	0.27	0.13	0.26	–0.50	0.14

[†] $p < 0.10$; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; $N = 11$

VAS was designed as a parallel rating to the parent-reported VAS. Children were asked “how are you feeling *right now*?” and rated their mood on an 11-point scale ranging from -5 to $+5$, whereby $-5 =$ “much worse mood than normal,” $0 =$ “normal mood for me,” and $+5 =$ “much better mood than normal.”

Procedures

The child-reported EMA protocol was embedded within the parent-reported EMA protocol described in Study 1. Following completion of the parent-reported EMA ratings, the parent was asked to indicate on the PDA if their child was able and willing to complete ratings. Parents were asked “can your child complete ratings right now?” and were asked to enter “yes,” “not able,” or “declines.” Parents were instructed to enter “declines” if the child explicitly refused to complete ratings and “not able” if the child was either otherwise occupied (e.g., playing a sport, completing homework, etc.) or unable to comply. To allow for assessment of the effects of emotion dysregulation with adherence to the protocol, parents were explicitly instructed *not* to attempt to enforce their child’s adherence to protocol.

If the child was willing and able to complete ratings, the parent was instructed to give the PDA to the child to enter self-ratings of mood and anger/irritability. To enhance children’s understanding of the ratings, children were provided with laminated “reminder cards” containing rating scales, verbal descriptions of numbers, and emoticons. To ensure that children’s ratings were not influenced by their parents, parents and children were explicitly instructed *not* to observe each other’s ratings. Child compliance was assessed by the ratio of completed to scheduled intervals, regardless of whether or not the interval was actually presented to the child (i.e., completed by the parent). The embedded protocol procedure was utilized to allow for assessment of the effects of children’s emotional

states on their ability to complete EMA ratings, as well minimize practical limitations that may negatively impact adherence (i.e., Suveg et al. 2010). No compensation was given to children for participation in the study.

Statistical analyses ANCOVA was used to assess the effects of child emotional distress on their completion of ratings. ANCOVA was conducted on the children’s parent-rated mood with child completion of the assessment interval specified as the grouping variable and children’s overall parent-rated mood entered into analyses as a covariate to control for individual variation in overall mood. Response bias was assessed by examining the psychometric properties of the children’s ratings and discordance from parent ratings. Correlation analyses were not employed within the present study given the small sample size.

Results

Feasibility of child-reported EMA procedures

Children’s adherence to the EMA protocol was assessed by calculating the percentage of scheduled EMA assessment intervals (intervals where the PDA signaled children and their parents) to the number of completed EMA assessment intervals (intervals where the children completed ratings). Children completed an average of 84.43 % of scheduled intervals (completed intervals: $M = 64.40$, $SD = 14.43$; scheduled intervals: $M = 76.27$, $SD = 5.66$), with 4 of the 5 children completing greater than 80 % of scheduled intervals.

Utility of child-reported EMA procedures

Overall, children were adherent to 321 intervals and were nonadherent to 28 intervals. ANCOVA indicated that parents rated their children’s mood as significantly poorer

during intervals where the child did not adhere to the EMA protocol ($M = -0.71$, $SD = 2.19$) than during intervals where the child was adherent ($M = 0.73$, $SD = 1.61$), $F(1, 346) = 16.56$, $p < 0.001$.

Qualitative examination of the child self-report EMA ratings in the present study suggested several concerns with response bias. Specifically, although the mood rating scale was anchored around 0, three of the five children provided mood ratings that averaged a full standard deviation or more above 0 (see Table 3). Children's mood ratings were markedly discordant from those of their parents, as children's responses differed by more than 1 rating value in 56.59 % (181 of 321) of all completed intervals, and 4 of the 5 children were discordant with their parents by more than 1 rating point in >40 % of intervals. As illustrated by Fig. 2, children had a tendency to use a dichotomous response style and rated their mood more positively than their parents in 89.50 % of intervals where there was a discrepancy of more than 1 rating value.

General discussion and future directions

The two studies provided an initial examination of the feasibility, utility, and validity of the use of Ecological Momentary Assessment methodologies to assess emotion dysregulation in children. Parents were consistently adherent to the EMA protocol, with an average completion rate of 86.53 % of scheduled intervals and 8 of 11 parents completing greater than 80 % of assessment intervals. Children also demonstrated considerable adherence to the embedded child-reported EMA protocol, with an average completion rate of 84.43 % of scheduled intervals and 4 of 5 children completing greater than 80 % of assessment intervals. Notably, these completion rates were achieved over a 4-week EMA assessment period, which was significantly longer than the one-week period in Whalen et al. (2006, 2009) parent-child report and Suveg et al. (2010) child-report only studies. Use of a longer assessment period offers several advantages, including ability to better capture the differential temporal patterns of emotion dysregulation (i.e., transient, chronic, episodic) that have been

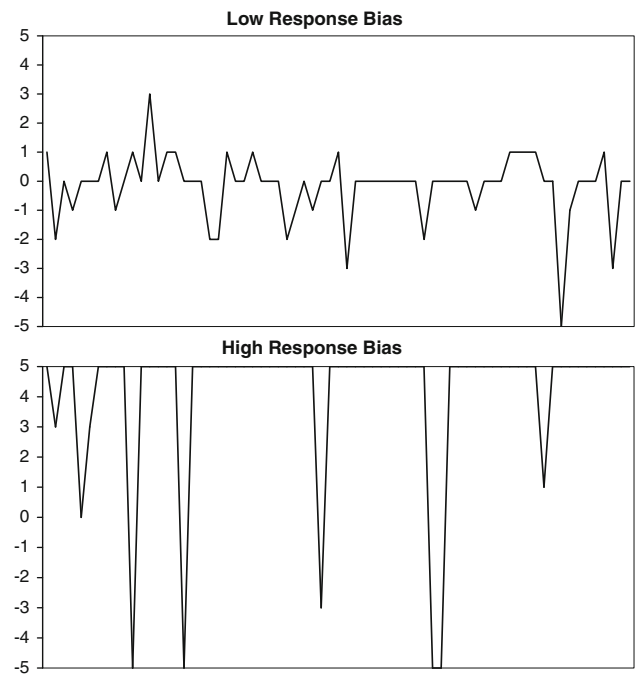


Fig. 2 Child-reported EMA ratings of mood selected to illustrate low versus high response bias (i.e., positive skew, dichotomous responding)

linked to distinct forms of psychopathology in children (Dickstein and Leibenluft 2006; Rosen and Epstein 2010) and ability to capture a broader and more representative temporal period of mood variation. Indeed, data from this study suggested only a small to moderate correlation between the first and second week of mood ratings, suggesting that a one-week period may produce a risk of either falsely inflated or suppressed mood variability and/or intensity. Overall, results suggested that use of a 4-week EMA based protocol was a feasible means of assessing emotion dysregulation in children.

Exploratory correlation analyses indicated that the aggregate intensity and variability of the parents' ratings of their children's mood were strongly associated with their questionnaire-based ratings of their children's emotional lability and emotional and behavioral distress, such that children who were rated as having more intense mood experienced more emotional variability and emotional and behavioral distress, and children who were rated as having more variable mood were also rated as demonstrating more emotional distress. All correlations were in the expected direction, with more intense and variable EMA-rated mood linked to greater emotional and behavioral dysfunction on conventional questionnaire-based ratings. Of note, none of the parent-rated EMA-based mood aggregates was related to children's questionnaire-based self-rated emotional difficulties. These results provide encouraging initial evidence of the validity of use of linearly derived aggregates of the

Table 3 Characteristics of child versus parent-reported EMA ratings

Child	Child mean	Child SD	Parent mean	Parent SD	% Discordance >1
G	-0.14	1.12	-0.16	1.22	6.15
H	1.36	2.02	0.12	1.52	41.03
I	4.21	2.46	0.18	0.76	96.15
J	3.36	2.17	1.09	1.95	70.00
K	3.01	1.61	1.69	2.04	53.62

EMA parent-reported ratings in the assessment of emotion dysregulation.

A particular strength of this study was its ability to assess and quantify not just conventional linear aggregates but temporally based nonlinear features of emotion variability as well. RQA results indicated that the *patterning* of mood variation was related to emotional lability and distress, but not to behavioral distress or socioemotional expression. Children who demonstrated a pattern of less recurrent, unstable mood states with more persistent variability were rated as experiencing more overall emotional distress than children whose mood states were more recurrent, stable, and intermittently variable. Overall, the results of the parent-reported protocol provided support for the use of RQA in the assessment of patterning of emotional variability, intensity, and distress in children.

In contrast to the encouraging utility and validity demonstrated by the parent-reported protocol in Study 1, the results of the child-reported protocol in Study 2 were considerably more mixed. The study demonstrated adequate adherence rates, indicating that children were able to adhere to a 4-week protocol with parental assistance. Embedding of the child-reported protocol within the parent-reported protocol produced an adherence rate comparable with Whalen et al. (2006, 2009) joint parent–child protocol and significantly higher than that of Suveg et al. (2010) child-only protocol, suggesting that parent involvement may be critical to maintaining child adherence rates. However, examination of the child ratings suggested that children were significantly more emotionally distressed during missed than completed intervals. This considerably limits the utility of child-report EMA assessment of mood, as it indicates that children may be least likely to complete assessment intervals (or parents may be least likely to provide children with the opportunity to complete assessment intervals) when their ratings would be most informative. Additionally, examination of the mood ratings suggested that children's use of the scale was markedly different from that of their parents, as three of the five children had mean mood ratings of greater than a full standard deviation above the central anchor point (“normal mood for me”). This use of dichotomous and positively skewed response style resulted in considerable discordance from parent ratings, compressed the range of responding, and reduced the overall relevance of the data.

While this study represented a small scale feasibility study, the results suggest several larger implications for the conceptualization, assessment, and treatment of emotional difficulties in childhood. Emotion dysregulation has emerged as a construct of substantial clinical and theoretical importance in recent years, yet there continues to be debate regarding both its definition and most valid means of assessment (Cole et al. 2004). It has become

increasingly apparent that “emotion dysregulation” actually represents a broad and multi-faceted range of processes, from in the moment inability to modulate emotional states to long-term difficulty maintaining a homeostatic and consistent mood state (Thompson 2011). Emotion dysregulation is by definition a temporal phenomenon, and the ability to capture and differentiate these nonlinear temporal patterns of variation is crucial. Among the most encouraging findings of the present study was the link between nonlinear patterning of emotional variability over time with conventional measures of emotional functioning.

Both the ability to collect longitudinal data about mood using EMA and to examine nonlinear patterns in the data using RQA represent significant progress toward the *quantification* of qualitatively different patterns of temporal emotional variation. Patterning of variability is a key component of the regulation of emotions which can only be captured through the use of temporal-based methodologies. RQA is a nonlinear analytic tool, and the present study represents a limited demonstration of the capability of RQA to quantify the dynamic structure of linear and nonlinear variation within time series. Future studies with larger samples, longer or more densely sampled time series, and/or more data points may reveal structure in higher dimensions, a prominent capacity of RQA analytic methods. Furthermore, the encouraging results of this study lend credence to the need for use of longer EMA assessment periods, such as the 4-week protocol employed in the present, so as to ensure that results more accurately approximate a child's true pattern of temporal emotional variation.

The need to identify and differentiate patterns of emotion dysregulation is particularly highlighted by the current debate regarding differential diagnosis of ADHD and Bipolar Disorder in children. Emotion dysregulation is a core component of both Bipolar Disorder and ADHD, and evidence increasingly supports the conceptualization of children within these groups as experiencing distinct *patterns* of emotion dysregulation (Dickstein and Leibenluft 2006; Rosen and Epstein 2010). Specifically, children with Bipolar Disorder by definition must demonstrate *episodic* mood variability, while children with ADHD and emotion dysregulation difficulties are more commonly conceptualized as demonstrating *chronic* mood dysregulation (Dickstein and Leibenluft 2006). The methodology of the present study has particular relevance to this issue given the ability of RQA to quantify dynamic and nonlinear patterns of variation. Accordingly, the Trend statistic of RQA (non-stationarity of the mean, indicative of episodicity) may be particularly relevant for differentiating Bipolar Disorder from ADHD in children, while statistics such as %Recurrence, MeanLine, and Entropy (stability and patterning of the mood variability) may be more useful for looking at variation *within* ADHD.

This study has several limitations that must be acknowledged. This study was conducted using a small sample size and exploratory analyses, which significantly limited the ability to draw conclusions regarding the relations of the EMA and questionnaire-based ratings. Similarly, the length of the EMA protocol, while substantially longer than in previous studies (i.e., Whalen et al. 2006, 2009; Suveg et al. 2010), limited the ability of RQA to fully unfold and quantify higher dimensional patterning of the time series data. The study did not assess ADHD symptoms or emotion dysregulation in parents. Given that there are substantial heritability estimates of both ADHD and emotion dysregulation (Barkley, 2010), it is possible that ADHD symptomatology and/or emotion dysregulation impacted parents' ability to adhere to the study procedures. However, it should be noted that most parents and children were able to demonstrate acceptable adherence to the EMA protocol over the 4 weeks. Additionally, the study did not account for parent mood when completing EMA ratings. Parent mood has been thought to influence parents' ratings of their children's behavior (Gartstein et al. 2009), and it is possible that parent mood may have influenced their ratings of the child's mood. Parent mood may have also influenced whether or not parents made the ratings available to their children to complete, which may explain in part the finding that parents rated children as demonstrating poorer mood during intervals when the child was unable to complete ratings. The study is thus best conceptualized as an initial pilot investigation of the potential of EMA and RQA in the assessment and quantification of emotion regulation. Accordingly, the primary focus of analyses was to examine the feasibility, utility, and validity of the methodology, rather than to establish an effect of the patterns of emotional dysregulation on behavioral or emotional functioning.

EMA presents several limitations as well. EMA-based ratings allow for multiple assessments of mood but do not provide information about context of the ratings. It was thus not possible to draw conclusions regarding why a child's ratings were elevated or decreased at any time point. EMA methodology is also particularly prone to producing missing data, as assessment intervals may be missed due to participant inattention or noncompliance, the presence of stressful life events, or even technical difficulties. Analysis of the child-reported ratings suggested a significant difference in mood ratings for nonadherent versus adherent intervals; however, the current methodology did not allow for an examination of a similar systematic bias in the parent-reported intervals. Specifically, the study did not assess parent mood during the EMA rating intervals nor did the EMA methodology provide a means for parents to decline to complete ratings due to parental emotional distress. Similarly, RQA does not account for missing data due to the assumption of

continuous homogeneous variation in data, and thus results are only reflective of completed rating intervals. Finally, the child-reported protocol described in Study 2 failed to yield useful data due to the presence of substantial response biases which precluded comparison of the discrepancy between parent's and children's perceptions of the child's mood fluctuations. Particularly, children demonstrated both a substantial skew toward the positive end of the scale (despite the middle of the scale being individually anchored to each child's 'normal' or usual mood state) and a strong tendency toward dichotomous responding. These findings have also been observed in a study that used EMA with a different response format in a larger same-aged community sample of children with ADHD (Rosen and Factor 2012). A full discussion and examination of why children were unable to accurately use the mood rating scale on repeated EMA assessment are beyond the scope of this paper but is something that will need to be addressed in future studies.

Conclusions

Emotion regulation is a critical element of childhood functioning; however, emotional dysregulation in children can take on many forms and differentiating patterns of dysregulation can be very challenging. Although, to paraphrase Justice Potter Stewart, everyone "knows it when they see it," the multidimensional nature of emotion regulation and dysregulation present particular challenges in attempting to define and differentiate patterns of emotion dysregulation in children. The present study provides initial evidence regarding the use of EMA and RQA to assess and quantify these facets of emotional arousal and fluctuation, which in turn has the potential to enhance our ability to differentiate patterns of emotion dysregulation in children. Further development and refinement of these methodologies hold promise for advancing the understanding of both the structural and functional nature of emotion dysregulation in children and has the potential to improve our ability to conceptualize, assess, and develop services to aid children who struggle with this fundamental emotional process.

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